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ABSTRACT

Land application systems are discussed with reference to the options available for applying wastewater and sludge to the site. Spray systems, surface flow methods, and sludge application schemes are all included with discussions of the advantages and disadvantages of each option within these categories. A distinction is made between the choice of treatment method and the application system. The selection of an application system is a function of the treatment alternative. Selection of alternative is made on the basis of fundamental soil, plant, waste and management factors pointing to overland flow, rapid infiltration, or irrigation as most appropriate for the given situation. Application systems described in this module include seven types of sprinkler irrigation techniques, gated pipe, three ditch systems, and the three most common field surface irrigation methods. Sludge spraying, spreading and subsurface injection are outlined. One important aspect of application system design is uniformity of wastewater contact with the treatment medium. This topic is addressed from a theoretical standpoint and related to the practical situation. A brief discussion of the special problems encountered in overland flow and rapid infiltration systems also is included. (Author/BB)

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Land Application of Wastes

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LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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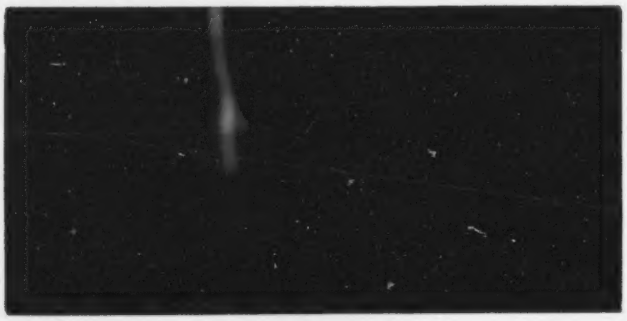

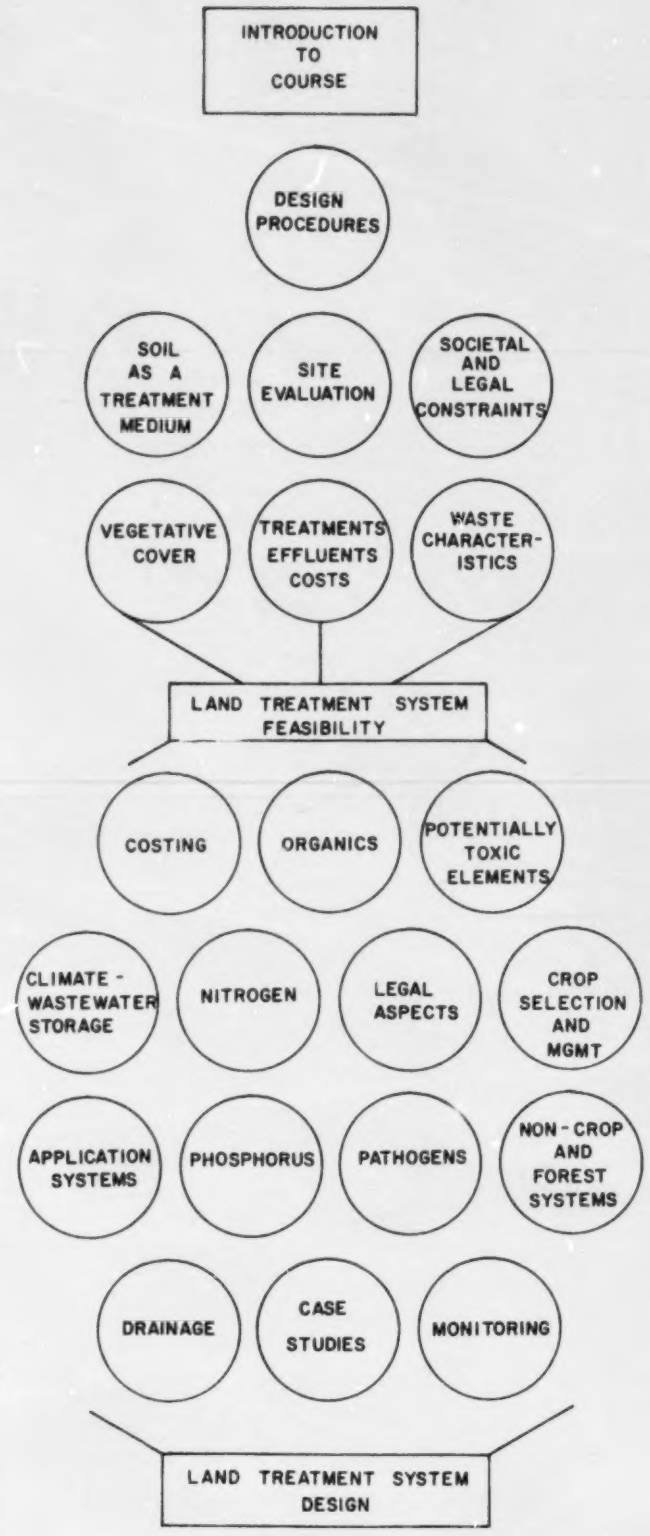

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WASTE APPLICATION SYSTEMS

Module 12

January, 1978

Summary

Land application systems are discussed with reference to the options available for applying wastewater and sludge to the site. Spray systems, surface flow methods, and sludge application schemes are all included with discussions of the advantages and disadvantages of each option within these categories.

A distinction is made between the choice of treatment method and the application system. The selection of an application system is a function of the treatment alternative. Selection of alternative is made on the basis of fundamental soil, plant, waste and management factors pointing to overland flow, rapid infiltration, or irrigation as most appropriate for the given situation. Once this decision is made, there will be several options available for application of the wastewater or sludge.

Application systems described in this module include seven types of sprinkler irrigation techniques, gated pipe, three ditch systems, and the three most common field surface irrigation methods. Sludge spraying, spreading and subsurface injection are outlined.

One important aspect of application system design is uniformity of wastewater contact with the treatment medium. This topic is addressed from a theoretical standpoint and related to the practical situation. A brief discussion of the special problems encountered in overland flow and rapid infiltration systems also is included.

Table of Contents

		Page
	Summary	i
	List of Figures	iii
	List of Tables	iv
	Objectives	v
I.	Introduction	1
II.	Site Characteristics	2
	A. Topography	2
	B. Soil	3
	C. Cover crop	4
III.	Application Techniques	5
	A. Sprinkler Irrigation	5
	1. Solid set	6
	2. Center pivot	8
	3. Side-roll, wheel move	13
	4. Continuous travel	14
	5. Towline lateral	15
	6. Stationary gun	15
	7. Traveling gun	17
IV.	Uniformity of Application	20
V.	Surface Irrigation	26
VI.	Overland Flow	30
	A. Design objectives	31
	1. Erosive flows	31
	2. Effluent quality	32
VII.	Rapid Infiltration	32
VIII.	Sludge Application	32
IX.	Bibliography	36

List of Figures

Figure		Page
1.	Solid set sprinkler irrigation	7
2.	Center pivot system	9
3.	Muskegon County wastewater management system No. 1	10
4.	Sprinkler patterns in use with center pivot irrigation systems	12
5.	Side-roll, wheel move distribution system (with and without trail tubes)	13
6.	Continuous travel system	14
7.	Towline lateral system and details of movement	16
8.	Traveling gun and typical layout for a traveling sprinkler system	17
9.	Idealized distribution and accumulation of irrigated water	21
10.	Solid set staggered spacing of sprinkler irrigation system	22
11.	Patterns of water application by a rotating type sprinkler operating at different pressures	22
12.	Application uniformity data for a 60 x 80 ft. solid set system	24
13.	Uniformity of application curves for a typical solid set system	25
14.	Gated pipe incorporates hand-adjustable openings	27
15.	Overland flow wastewater distribution system	30
16.	Economic analysis of sludge application systems...with various sizes of tankwagons	34

List of Tables

Table		Page
1.	Treatment alternative vs. site characteristics	3
2.	Characteristics of major types of spray disposal systems	19

Objectives

Upon completion of this module, the reader should be able to:

1. List the application systems alternatives which are applicable to each of the following:

   Spray irrigation
   Surface irrigation
   Overland flow
   Rapid infiltration

2. Discuss the advantages and disadvantages of the seven types of spray application covered in the module.

3. Discuss the crop limitations of the surface irrigation methods, and identify the spray systems which impose limitations on crops which may be grown.

4. List the application methods appropriate for sludge and discuss their advantages and disadvantages.

5. Define "coefficient of uniformity" and discuss the importance of uniformity of application to waste application sites.

6. Name the best sources of engineering advice on waste application systems.

Introduction

An integral part of land treatment is the physical transport and application techniques utilized in dispersing wastewaters and sludges on the land. The system selected must satisfy many demands imposed upon it by the waste constituents, the application site characteristics, economic considerations, type of land treatment systems, and the law. Because each system design is highly site specific, many variations will emerge across the country.

Techniques used for water distribution in irrigated agriculture have been successfully adapted to land application systems for wastewater renovation. This is good practice in that stocks of pipes, nozzles, valves, gates, etc. are readily available for the initial installation, and parts and maintenance assistance can be obtained easily from the irrigation equipment supplier. However, use of irrigation equipment "off the shelf" without any adaptation for wastes application has led to systems which have been badly designed and in some cases resulted in complete failures (Norum, 1976). Many irrigation equipment manufacturers have developed expertise in land treatment, and it is best to obtain advice from their applications engineers.

Selection of waste application systems should not be confused with the selection of the method of land treatment (i.e. spray or surface irrigation, overland flow, rapid or moderate rate infiltration, etc.). Selection of treatment method is a more basic decision which then leads to the selection of application system alternatives. The factors contributing to treatment method evaluation are discussed in several other modules in this program, including Modules 3, "Soil as a Treatment Medium"; 2, "Site Evaluation"; 5, "Waste Characteristics"; 11, "Potentially Toxic Elements"; 9, "Pathogens"; 15, "Nitrogen Considerations"; and 19, "Phosphorus Considerations"; and will not be discussed here in any detail.

Site Characteristics Influence Selection, Design of System

Site characteristics which greatly influence the selection and design of waste application systems are topography, soil, and the cover crop desired. It is difficult to discuss individual site parameters without drawing upon other factors which influence their behavior. The availability of certain soils, topography, and depths to bedrock will be factors affecting the type of treatment system designed. Slope conditions may dictate the type of crop that is needed for the soil encountered. This in turn may dictate the application system needed to attain the required effluent quality. Site characteristics are discussed at length in Module 2, "Site Evaluation." An understanding of the interrelationships of the characteristics of specific sites is necessary to approach a maintenance free system with a simple management scheme.

The topography, soil, and vegetative cover of the site greatly influence the selection and design of the waste application system.

Topography Limits Method of Wastewater Application

The topography of the treatment site limits the method of wastewater application. Systems depending upon rapid infiltration of the wastewater must be relatively level (0-1% slope) whereas systems utilizing slow to moderate infiltration rates may vary from 0 to 10+% slope. Large rotating sprinkler irrigation rigs have the mechanical power and flexibility to be utilized on slopes of 15 to 20% (Norum, 1976), although erosive flows have resulted with these big rigs upon steep slopes. Overland flow systems have been successful on slopes ranging from 2 to 8%, and the site may be shaped to meet the needs of this treatment method. With methods other than shaped overland flow, the soils and slopes are generally accepted as they occur, however, and the length of run and volume of water applied are varied as needed to

Soil and slope of the site usually are not altered to fit a certain treatment method; rates of water application are adjusted to fit the site characteristics.

prevent erosive flows and to attain the required effluent quality. Surface irrigation systems are designed to accommodate existing soils, slope, and cover crop conditions. The rate at which water is applied is dependent upon these factors as well as the type of irrigation system utilized.

Soil Structure and Permeability Must be Able to Withstand Loadings

Soil conditions at the treatment site play an important role in selecting and managing a wastewater application system. Soil permeability is the major consideration in the infiltration and percolation capacity of the soil profile. Rapidly, moderately, and slowly permeable soils, along with optimum land slopes, relate to the land treatment alternatives as shown in Table 1. The ability of the soil structure to maintain its integrity under hydraulic stresses as well as vertical loadings from irrigation rigs and crop management equipment must be investigated prior to application system selection. This is especially true where wastewater renovation is secondary to crop production schemes. The soil and slope available to the system has a great deal to do with the method of application, especially where crops are surface irrigated and nonerosive flows are to be expected.

The ability of the soil structure to maintain its integrity as well as permeability under saturated conditions limits the application system selected.

Table 1: Treatment Alternative vs Site Characteristics

Treatment Alternative	Soil Permeability	Topography	Cover Crop
Rapid Infiltration	moderate to rapid	0-1%	Generally none
Overland Flow	slow	2-8%	pasture grasses
Irrigation			
Sprinkler	slow to rapid	0-15%	any
Surface	slow to moderate	0-8%	any

Type of Cover Crop Bears Directly on Choice of Application System

The cover crop planted on the treatment site may be selected with wastewater renovation foremost in mind, or the wastewater renovation system may have to be adapted to crop management schemes suited to the available land. In either case, the cover crop used will have a direct bearing on the application system selected. Surface irrigation systems are generally soil, slope, and crop specific. Flood irrigation is generally used with close grown crops such as pasture and grain crops whereas furrow or corrugation application systems are more adapted to row crops such as corn, sugar beets, or sorghum. Corrugation irrigation is a method which entails the creation of shallow, closely spaced furrows through the use of a special tillage implement. This technique is discussed in a later section of this module.

The cover crop at the site has direct bearing on which application system to select: surface irrigation is suited to close-growing crops, furrow and corrugation systems for row crops and sprinkler irrigation can be adapted to all vegetative covers.

Sprinkler irrigation systems are adaptable to all vegetative cover situations. However, portable sprinkler systems are dependent upon soil and topographical limitations as well as the vegetative cover height. In order to control nonpoint sources of pollution such as sediment and nutrient runoff, cover crops must be evaluated in relation to the irrigation volume, site topography, and soil conditions. Crop and other vegetative cover considerations are examined in depth in Modules 20 "Crop Selection and Management Alternatives" and 13 "Non-crop and Forest Systems".

To control runoff, cover crops must be considered in relation to irrigation volume, site topography and soil conditions.

Application Techniques

Sprinkler Irrigation: Sprinkler irrigation is being used in many parts of the country to apply wastewaters and sludges to the land. Wastes containing less than 10% solids are readily dispersed in this manner. These solids must be small and uniformly distributed throughout the wastewater in order to achieve uniform application and to avoid system clogging. Gross solids must be removed to protect pumps and spray nozzles from clogging and undue wear. Equipment manufacturers have developed sophisticated systems over many years of sprinkler irrigation design experience. Although systems are available which can meet the requirements of wastewater application, care must be taken that the sprinklers can handle the solids loading or other special needs of a waste treatment system.

For most successful sprinkler irrigation, wastewaters should have no more than about 10% solids.

Sprinkler irrigation systems in common use today include a variety of design schemes that have survived years of rigorous field trials. The systems discussed in this module are:

1. Solid set, both buried and above ground
2. Center pivot
3. Side-roll, wheel move with or without trail tubes
4. Continous travel
5. Towline laterals
6. Stationary gun
7. Traveling gun

Sprinkler systems commonly used today have a variety of design schemes which have survived years of rigorous field trials.

The portability of these systems within the treatment site depends upon the irrigation scheduling and management scheme utilized. All the systems listed above, except for the buried solid set system, are designed to be relatively portable. Even the large center pivot systems can be towed from one water source to another by a farm tractor. Because of the intensity of use

Except for a completely underground solid set system, some degree of portability is built into all sprinkler irrigation systems.

expected in wastewater renovation systems, center pivot rigs will more than likely remain in one location and be thought of as permanent. Main lines for all of these systems will probably be permanently buried. This provides protection from freezing weather and surface loadings from large farm machinery, as well as other hazards.

Spray application systems are appropriate for crop irrigation and, in some cases, overland flow systems. In general, they allow disposal on sandy soils where high infiltration would make surface application very difficult, and spray systems are often the most economical for irregularly shaped or rolling terrain. Initial installation costs are generally highest for sprinkler systems, but labor requirements can be less than surface irrigation, and automation is possible.

Spray application is appropriate for crop irrigation, some overland flow systems, sites with sandy soil and sites with irregularly shaped or rolling terrain.

Solid set irrigation systems can be permanently buried systems or laid on the ground surface and moved by hand between irrigated fields, in which case the equipment can be collected and stored during the non-application season. The term "solid set" refers to the fact that the system has no moving components during a spray period, not that it is totally immobile. Main lines and laterals are laid out in a grid pattern to cover the irrigated area. Overlap between sprinklers varies between 30 to 60% of the wetted diameter. This overlap is needed for uniform water distribution.

Solid set irrigation systems may be automated and can be portable if laterals are laid above ground.

Equipment manufacturers have developed an array of automatic valves which may be regulated from a main control point. In this manner the entire system could be scheduled on a time clock and programmed to run continuously. Continuous surveillance of the system would still be required to make adjustments and maintain the equipment.

Systems can be programmed to run continuously via an array of automatic valves. This eliminates much hand labor but not the need for constant surveillance.

Figure 1 is taken from a design example in an equipment manufacturer's handbook. This layout represents a permanent solid set system in an orchard. The sprinklers are spaced to give most efficient coverage, and the lateral pipelines are laid diagonally to the main. This configuration is most economical, minimizing overall length versus size of laterals required, and cutting the number of valves and connections to the main line to approximately half of those in a system employing laterals along each row. If a moveable solid set system were used for this application, the rectangular grid layout would probably be favored due to the ease of moving laterals along the straight rows. The extra money spent on valves and fittings in this case would be made up by only having enough laterals and nozzles for partial coverage of the site and moving them between sets.

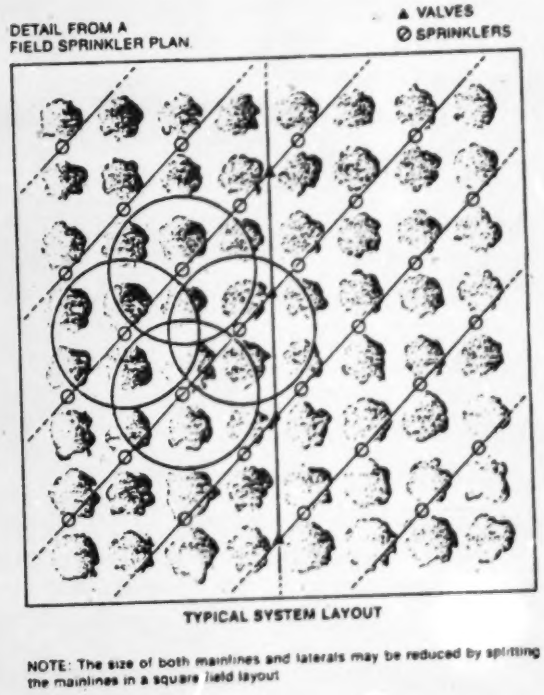

DETAIL FROM A
FIELD SPRINKLER PLAN
▲ VALVES
⊘ SPRINKLERS
TYPICAL SYSTEM LAYOUT
NOTE: The size of both mainlines and laterals may be reduced by splitting the mainlines in a square field layout

FIGURE 1. Solid Set Sprinkler Irrigation, (Fry and Gray, 1971).

The principal advantages of a permanent solid set system are the possibility of automation and reduced labor demands. Disadvantages are high cost, generally too high to be economically feasible for all but very small systems which can use small diameter pipe, and the necessity of protecting risers and nozzles from equipment and animals.

A permanent solid set system can be automated, thus reducing the amount of labor needed. Movable solid sets have low initial cost but high hand labor requirement.

Hand move solid set systems generally use 20 to 40 foot sections of lightweight aluminum pipe joined by couplers with sprinklers built in. Advantages and disadvantages of the hand move solid set systems are:

Advantages:

- Low initial cost
- Used systems available
- Few mechanical parts
- Low power requirements (50 psi at the sprinklers)
- Flexible in coverage of area and shape of site

Disadvantages:

- High labor requirement
- Sections disassembled and moved by hand
- Small sprinkler outlets

Center pivot distribution systems, shown in Figure 2, cover up to 640 acres (a one square mile "full section") with a half-mile long boom with end units spraying the corners of the field. They are composed of a complex system of towers, pipes, guy-wires, and motorized wheels. Circular distribution patterns result from center pivot units, although telescoping end units have been developed to cover the triangular corner pieces also. These systems are generally thought of as permanent installations, but quick-disconnects at the "water source" end provide for easy detachment. The wheels may be turned parallel to the main distribution line thereby allowing the system to be towed from one center pivot point to another. These systems distribute large volumes of water which cause localized saturation of the soil. Because the weight of the entire system rests upon the various tower wheels, the wheels are susceptible to becoming mired down in mud. Decreases

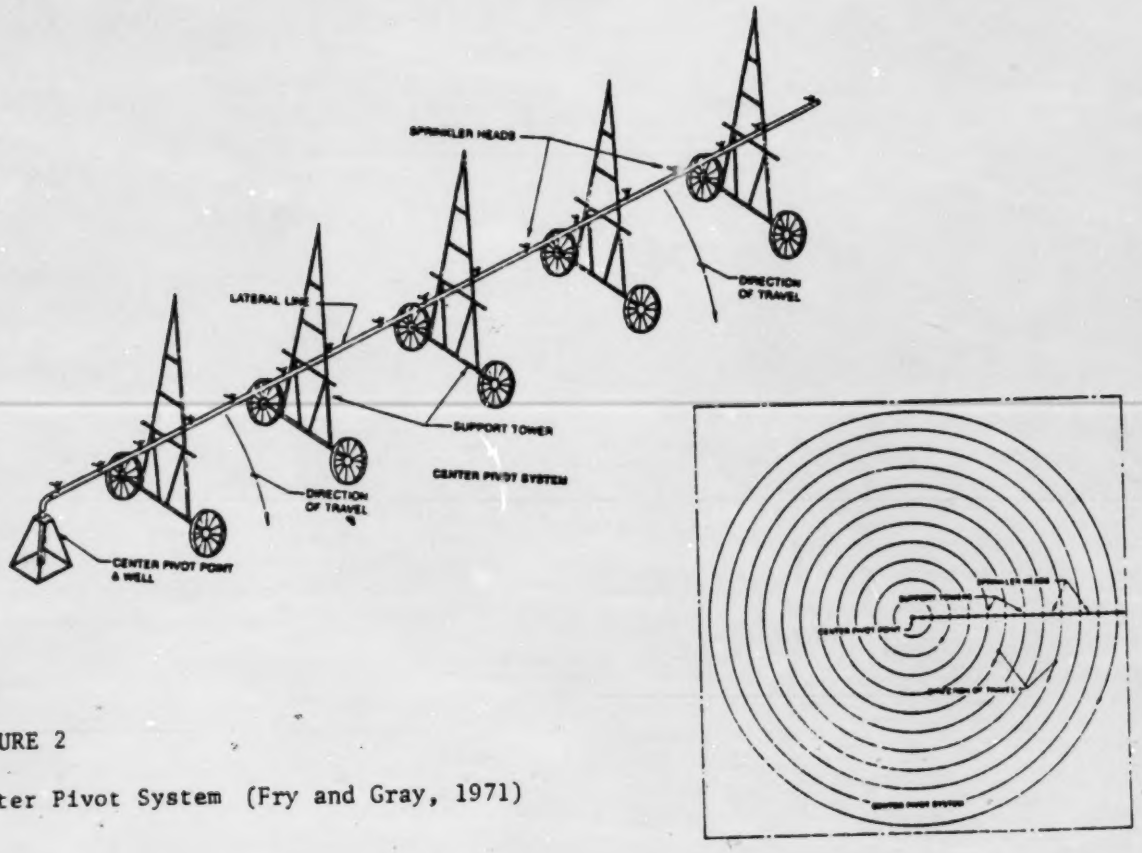


FIGURE 2

Center Pivot System (Fry and Gray, 1971)

in application rates and various design changes of the wheels have kept these problems to a minimum.

The Muskegon County Wastewater Management System No. 1 utilizes 54 center pivot irrigation rigs to irrigate approximately 5400 acres of farmland with minicipal and industrial wastewater. The irrigation spray rig costs were approximately $382/acre whereas the total irrigation spray system costs were approximately $1,285/acre, including distribution piping, pumps, and other equipment and preparation. Application rates average 2.5 in/wk with maximum rates of 4 in/wk. The system layout is shown in Figure 3.

Center pivot systems can cover up to 640 acres per unit, disdistirubting large volumes of water which cause localized saturation of the soil. Muskegon County Wastewater Management System No. 1 uses 54 of these rigs to irrigate 5400 acres. 100 acre coverage is in the average size range for center pivot rigs used in irrigated agriculture.

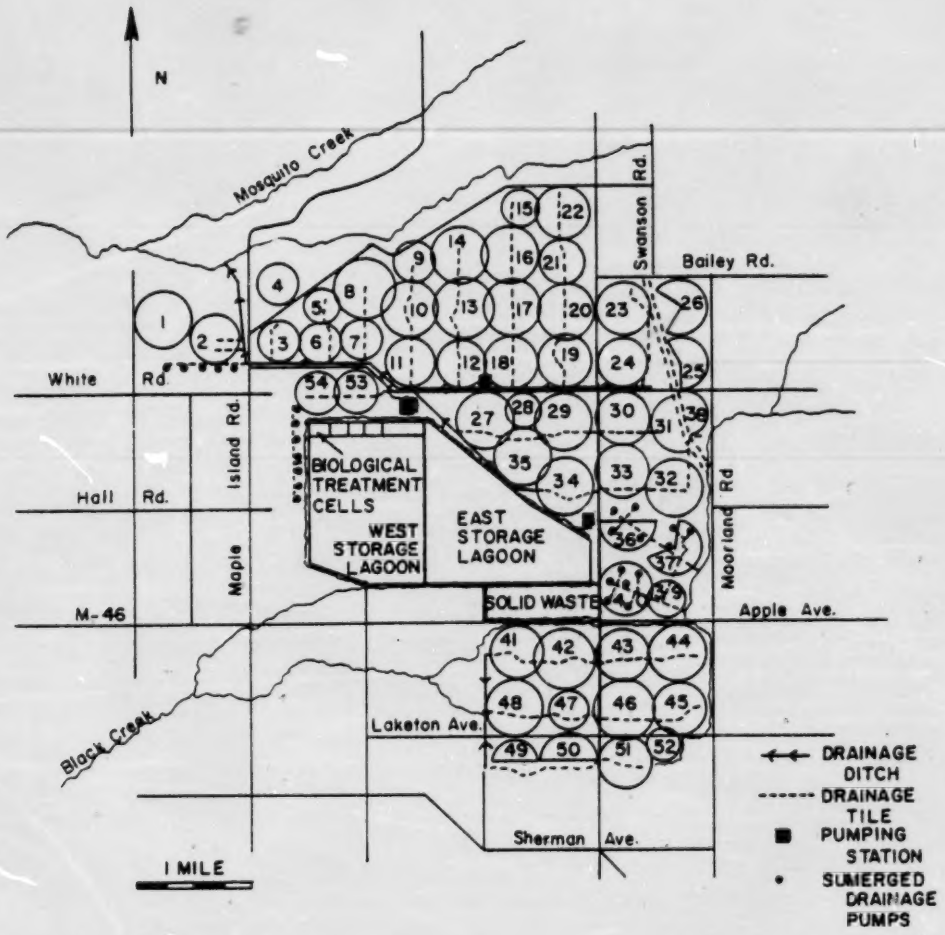


Figure 3. Muskegon county wastewater management system No. 1. (Demirjian, Y.A. 1965)

Figure 4 illustrates the three most common patterns of sprinkler nozzle spacing and sizing in use with center pivot rigs. Advantages and disadvantages of the three patterns are noted. The fixed spacing with variable sprinkler size, (Figure 4b), generally would be the least amenable to wastewater application due to the higher operating pressures required, more soil compaction, and less uniform precipitation rate. The first consideration results in higher operating costs for pumping, and the latter two affect the treatment efficiency of the site. Soil compaction will reduce infiltration capacity and can affect the water application rate which may be used. Uniformity in spray application rate is necessary in order not to exceed the design application rate in any area of the field. This topic of application uniformity will be addressed in some detail in a later section of this module.

Center pivot systems have at least three options for nozzle design and spacing available from the manufacturer. The option selected must meet the treatment requirements of the site.

The spray flood jet pattern uses downward-facing nozzles (Figure 4c) and results in lower power requirements. Plugging problems are listed if "gravel" is pumped, but wastewater solids should not pose a problem. This type of sprinkler pattern is used at Muskegon. An additional advantage of downward spraying is that aerosol production is minimized with lower operating pressure, and those which are formed are not airborne to be transported by the wind as readily as aerosols from higher pressure systems.

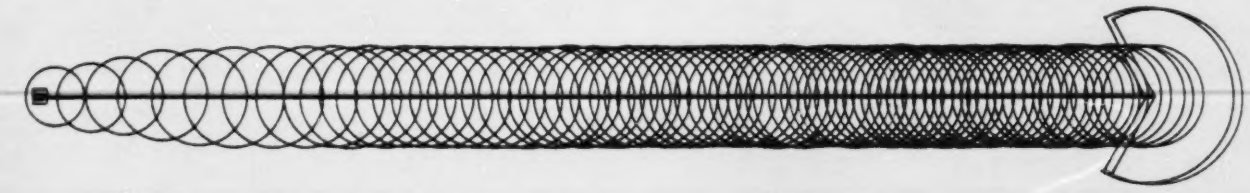
The advantages and disadvantages of center pivot systems can be summarized as follows:

Advantages:

- Almost complete automation
- Can use various types of sprinkler patterns
- Can be cost-effective for larger systems
- Even coverage of field area

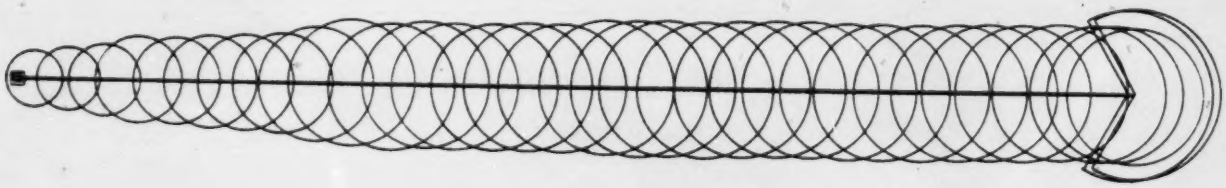
4(a). VARIABLE SPRINKLER SPACING PATTERN (Top View)

1. Uses approximately the same size sprinklers along the entire length of the system with the space between sprinklers decreasing as you move out from the pivot.
2. Requires lower operating pressure than the fixed spacing.
3. Less Soil Compaction than with the fixed spacing due to smaller droplet size.
4. More sprinklers used for a given length system than the fixed spacing. This results in lower G.P.M. per sprinkler which provides a uniform precipitation rate along the length of the system.
5. The width of the water pattern is approximately the same throughout, this results in a slightly higher precipitation rate than the fixed spacing.



4(b). FIXED SPRINKLER SPACING PATTERN (Top View)

1. Uses sprinklers of varying sizes spaced evenly along the system with the size of the sprinklers increasing as you move out from the pivot.
2. Requires higher operating pressure than the variable spacing.
3. Higher soil compaction than with the variable spacing due to larger droplet size.
4. Less sprinklers used for a given length than with the variable spacing. This results in higher G.P.M. per sprinkler which provides a less uniform precipitation rate along the length of the system.
5. The water pattern is wider at the end of the system getting narrower as you move in toward the pivot. This gives a slightly lower precipitation rate than with the variable spacing.



4(c). SPRAY FLOOD JET PATTERN (Top View)

1. Uses flood jet spray nozzles of different sizes variable spaced along the length of the system. (Nozzles increase in size and are spaced closer as you move out from the pivot.)
2. Causes the least amount of soil compaction because of the extremely small droplet size.
3. Requires lower operating pressure, (20 to 25 P.S.I. lower than comparative fixed or variable spacing), which results in lower H.P. requirements and operating costs.
4. The water pattern in narrower and results in a higher precipitation rate than the fixed or variable spacing, therefore soil intake capabilities will have to be considered.
5. If a well pumps large gravel there may be some problems with the nozzles plugging.

Figure 4

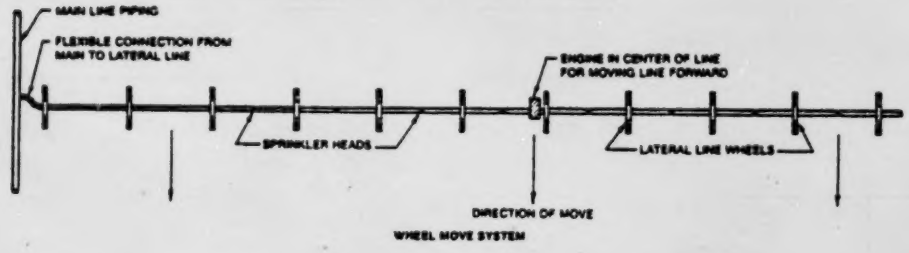
Sprinkler patterns in use with center pivot irrigation systems. (Lindsay, 1977)

Disadvantages:

High cost per individual rig
Fixed area coverage
Many mechanical parts
Small sprinkler outlets

Side-roll, wheel move systems eliminate hand labor in moving and provide good coverage for growing crops.

Side-roll, wheel move systems with and without trail tubes are shown in Figure 5. Because wheel diameters are available in sizes up to 8 feet, the mature cover crop should not exceed 4 feet in height. The system is stationary while spraying takes place, then is moved to the next set. An engine mounted in the middle of the pipe axle propels the system from one irrigation set to another.


MAIN LINE PIPING
FLEXIBLE CONNECTION FROM MAIN TO LATERAL LINE
ENGINE IN CENTER OF LINE FOR MOVING LINE FORWARD
SPRINKLER HEADS
LATERAL LINE WHEELS
DIRECTION OF MOVE
WHEEL MOVE SYSTEM

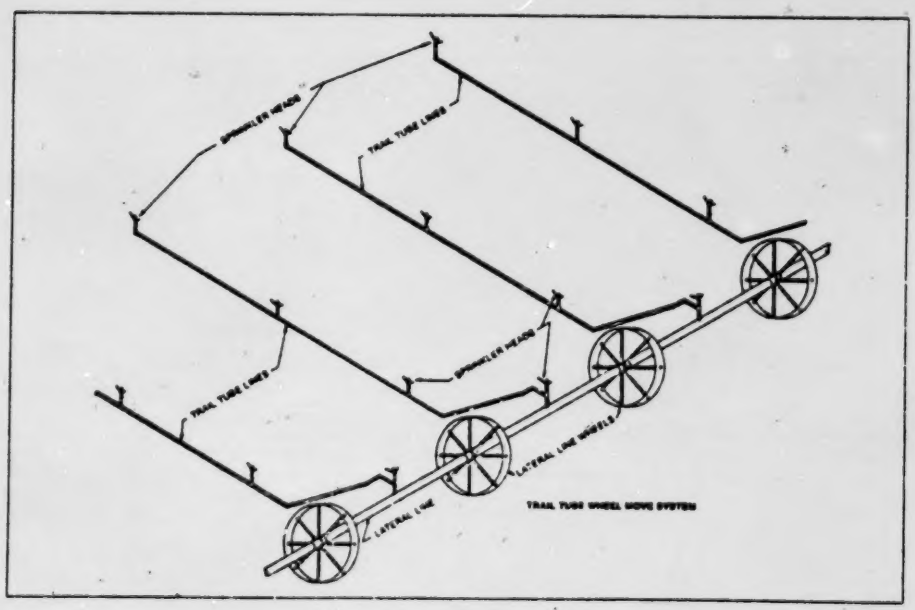


Figure 5. Side-roll, wheel move distribution system (with and without trail tubes), (Fry and Gray, 1971)

Advantages:

Eliminates hand labor in moving

Good coverage for close-growing crops

Disadvantages:

Rectangular field shape only

Can have alignment problems

Restricted height of crop

Can have mechanical problems

Continuous travel distribution systems, Figure 6, utilize a flexible supply line which is dragged along behind the continuously moving lateral line. This flexible line may allow only one irrigation set per day. Advantages and disadvantages are the same as those for the side-roll; wheel move system.

Continuous travel distribution systems have the same advantages and disadvantages as side-roll, wheel move systems.

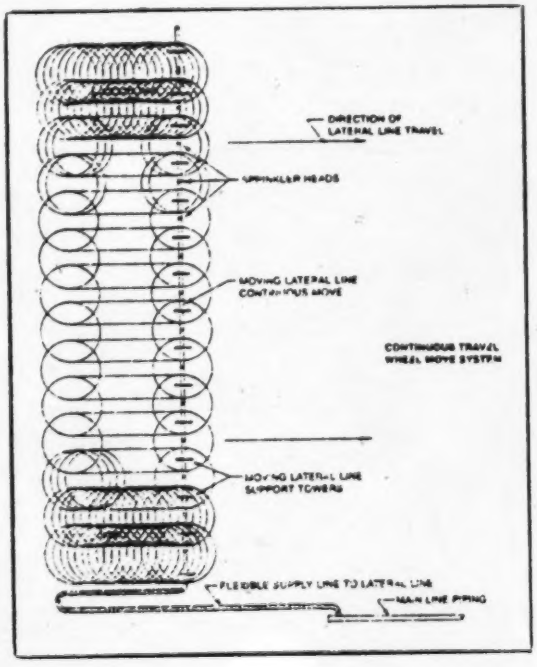


Figure 6. Continuous travel system (Fry and Gray, 1971)

Towline laterals, Figure 7, are towed from one irrigation set across the main delivery line to another set, following a scheduled pattern. One suggested pattern is shown in Fig. 7(b). Fig. 7(c) illustrates a system with a buried main line and hydrant connections for the moveable laterals.

The towline lateral system has stronger couplings between the pipe sections, but is otherwise much the same as a hand move solid set system.

The towline lateral system has stronger couplings between pipe sections than the hand move solid set system but otherwise is similar.

Advantages:

- Low initial cost, comparable to hand move
- Lower labor requirement
- Few mechanical parts
- Low power requirement (50 psi at the sprinkler)

Disadvantages:

- Not flexible in land area coverage because of difficulty in adjusting lateral length
- Small sprinkler outlets
- Tractor required
- Driving lanes required for tractor

The stationary big gun system consists of a single large-bore rotating sprinkler head which is connected to the distribution piping and moved between sets by hand. Typical application rates are comparable to hand move solid set systems. The big gun is capable of spraying slurries with its large diameter nozzle.

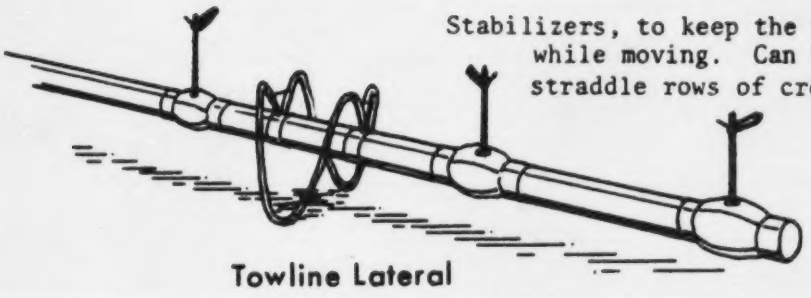
The stationary big gun can spray slurries with its large diameter nozzle and is currently used for sludge application.

Advantages:

- Low initial investment
- Few mechanical parts
- Few plugging problems with large nozzle
- Flexible in land area
- Pipe diameter can be slightly less than with small sprinkler
- Capable of spraying sludge slurries

Disadvantages:

- Higher power required for large outlet (80 psi at the sprinkler)



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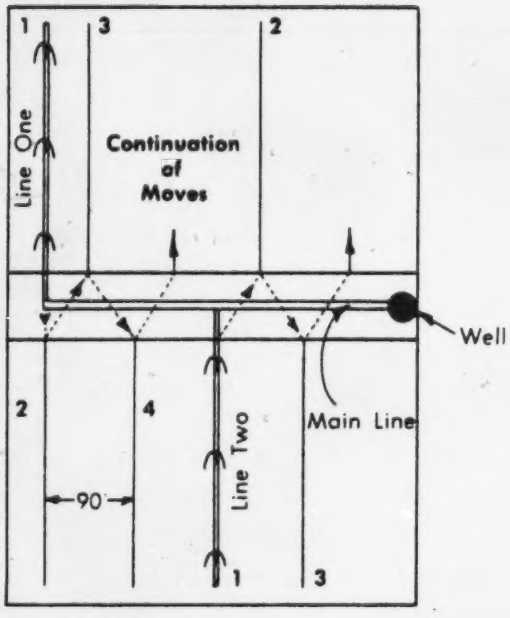

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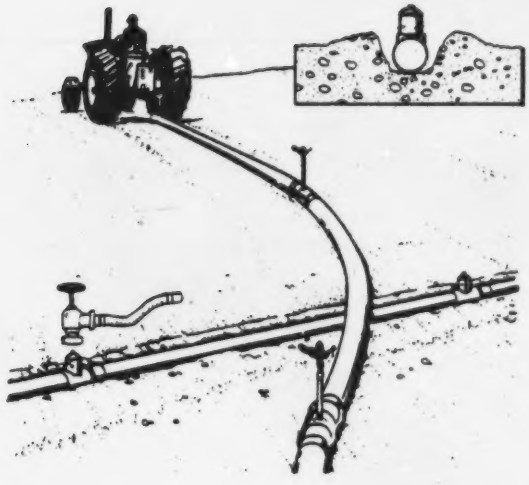


(c)

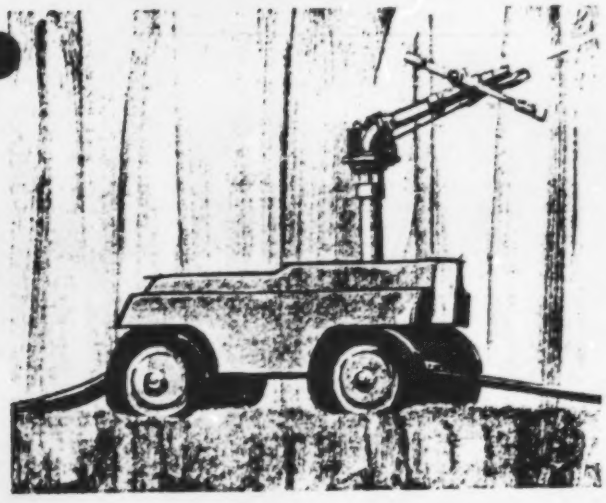
Figure 7

Towline lateral system and details of movement (Lindsay, 1977).

High labor requirement
Distribution not uniform in windy conditions
High aerosol transport

The traveling gun distribution technique, Figure 8, utilizes the same big gun nozzle mounted on a cart. These systems have a flexible supply line which is dragged along behind the cart. This hose is a major cost item in the system. The cart may contain a running gear and be towed by a pull cable or it may have hydraulic motors to propel the wheels. Various configurations are available from several manufacturers. The traveling big gun has been extensively used for wastewater and sludge application. One common size traveling gun will irrigate 10 acres per set, compared to the same size stationary gun's 2 acres per set.

The traveling gun can irrigate up to 5 times the acreage per set than a stationary gun of the same size.



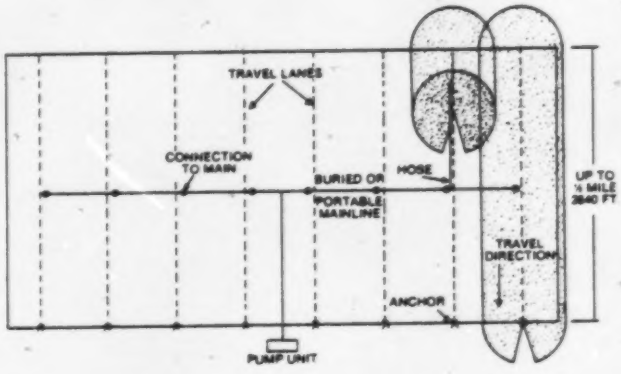


FIGURE 8.

NELSON Big Gun & Typical Layout for a Traveling Sprinkler System (Nelson, 1977)

Advantages:

Very low labor requirement

Few plugging problems

Flexible in land area and topography

Capable of spraying sludge slurries

Disadvantages:

High initial cost

High power requirement

Many mechanical parts - can have auxilliary gas engines on the carts

Table 2 presents a comparison of the most widely used spray irrigation systems, in terms of characteristics important to waste application.

TABLE 2: Characteristics of major types of spray disposal systems (adapted from Norum, 1976)

Type of System	Maximum Field Slope %	Ave. Water App. Rates in./hr Min	Max	Field Shape	Field Surface Conditions	Max. Crop Height ft	Labor Required hrs/ac.irr.	Size of Single System, acres	Approximate Cost, $/acre[a]	Wind Drift Hazard	Solids Handling Capability	Comments
Portable solid set[b]	no limit	0.05	2.0	any shape	no limit	no limit	0.20-0.50	no limit	400-900	average	poor	Well-suited for field crop and forest disposal sites
Buried solid set	no limit	0.05	2.0	any shape	no limit	no limit	0.05-0.10	no limit	400-1000	average	poor	Well-suited for small systems spraying field crops where completely automatic operation is required
Side wheel roll	5-10	0.10	2.0	rectangular	reasonably smooth	3-4	0.10-0.30	20-80	100-300	average	poor	Best suited for periodic spraying of industrial wastes (such as cannery wastes) on field crops
Traveling gun	no limit	0.20	1.0	rectangular	roadway for hose and sprinkler unit	no limit	0.10-0.30	40-100	120-250	high	excellent	Well-suited for spraying sludge on field crops as demonstrated by Metrol. San, Dist. of Greater Chicago, Fulton County, IL
Center pivot	5-15	0.005	0.090	circular	clear of high obstructions, path for towers	8-10	0.05-0.15	40-160	180-350	low	average	Well-suited for large-scale spraying of wastewater on field crops as demonstrated at Muskegon, Michigan

[a]Does not include cost of water supply, pump, power unit and mainline. Best source of equipment and cost information is irrigation systems vendors.

[b]Towline lateral system is same except that field shape is not as flexible, labor requirements are substantially less.

Wastewater Application Should be Uniform for Effective Treatment

In the design of spray irrigation systems each unit area of soil is expected to accept a designated volume of wastewater. If, however, the wastewater volume is not applied evenly to the renovation site, treatment is circumvented.

A means of quantifying the uniformity of application of sprinkler systems is the Uniformity Coefficient (or Christiansen's U.C., after the developer). It is expressed as a percentage and defined by the equation:

$$C_u = 100(1.0 - \frac{\Sigma x}{mn})$$

Wastewater must be applied uniformly over the soil so that the soil can receive the design application rate without over- or under- loading of large areas.

where

Σx = Sum of deviation of individual observations from the mean

m = Mean or average values

n = Number of observations

In order to determine C_u in a field situation, containers are spaced in grid fashion over the wetted area to catch the irrigated water. An ideal application situation would result in the pattern of Figure 9, which indicates the overall uniformity achieved by the cumulative pattern of several individual sprinklers arranged in a row. Manufacturers often provide suggested sprinkler patterns to achieve as uniform an application as possible for given conditions. Figure 10 is an example of this, taking wind direction into account. The coefficient of uniformity (C_u) for sprinkler irrigation systems may be as high as 90%. However, values in the mid-70's are more realistic. Higher C_u values may be attained where the need justifies the additional expense.

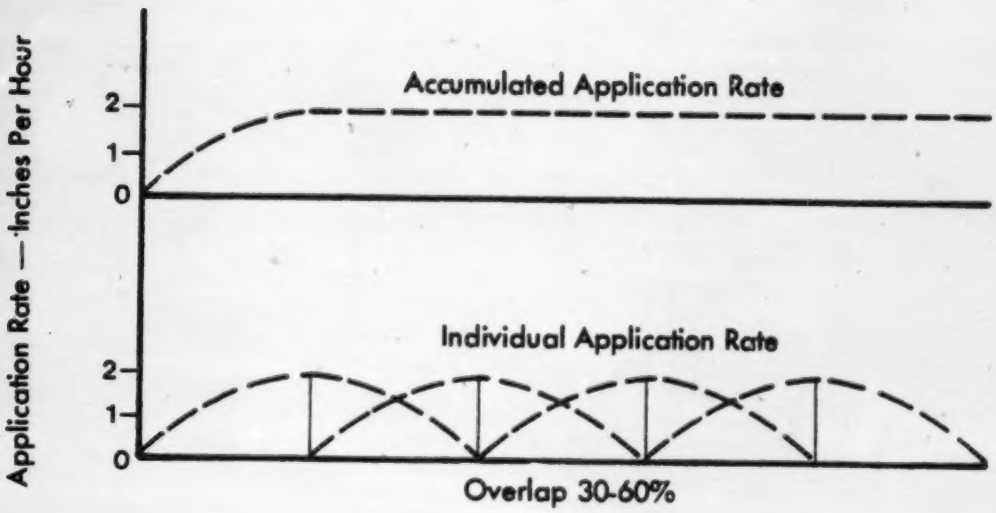


Figure 9. Idealized Distribution & Accumulation of Irrigated Water from Four Sprinkler Nozzles

The factors which influence the uniformity of application are:

1. The sprinkler selected
2. The grid spacing utilized and degree of overlap
3. The nozzle size and operating pressure
4. The wind speed

Sprinkler manufacturers publish data associated with their equipment, which aids the designer in determining many design parameters, including C_u. The nozzle size, pressure rating, gallons per minute flow capacity, and the wetted diameter are standard specifications in any sprinkler irrigation design. Typical distribution curves for a given nozzle at a given pressure are also available. These curves are used in conjunction with the desired grid spacing to attain a uniform application.

Manufacturer's information on sprinkler equipment includes includes nozzle size, pressure rating, flow capacity in gallons per minute, and the wetted diameter.

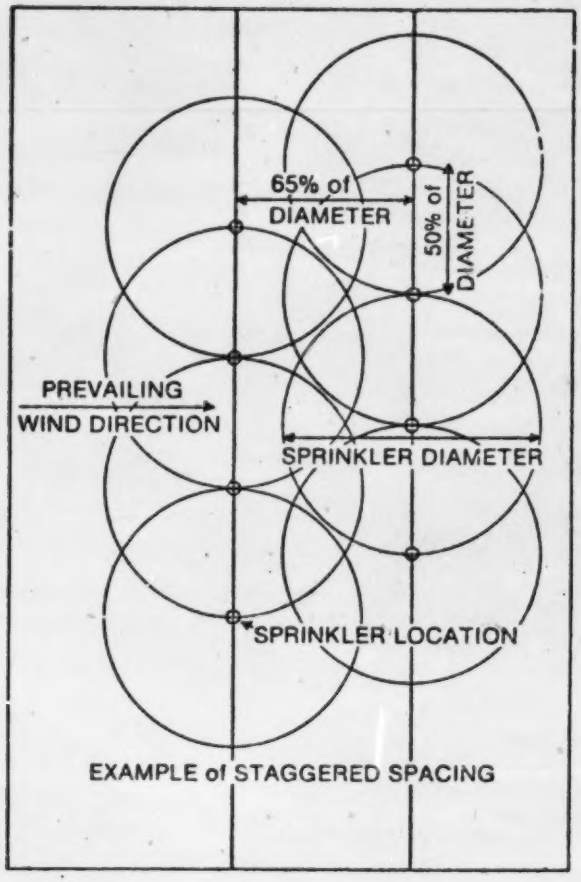


Figure 10. Solid set staggered spacing of sprinkler irrigation system, (Nelson, 1977)

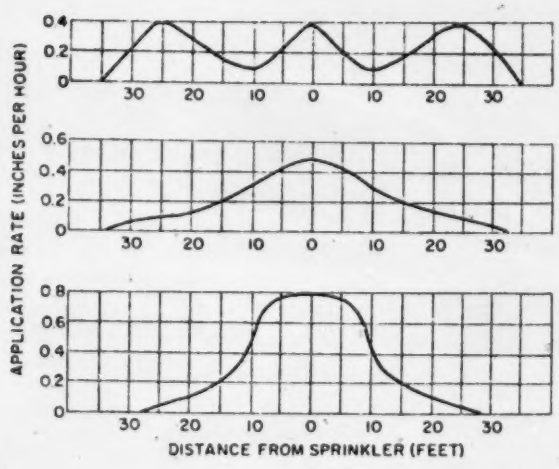


Figure 11. Patterns of water application by a rotating-type sprinkler operating at different pressures: (Top), pressure too low; (Middle), pressure satisfactory; (Bottom), pressure too high. (Quackenbush, 1957)

If operating pressures are not maintained as designed, different distribution patterns result as shown in Figure 11. Very large quantities of water could collect over individual areas, possibly exceeding the infiltration or percolation capacity of that area and causing saturation and ponding.

If operating pressures of sprinklers are not maintained as designed, very large quantities of water could collect over certain areas and exceed the infiltration or percolation capacity of that area, causing saturation and ponding.

The distribution curves resulting from trial runs of various sprinkler models were arrived at through the use of water. If a thicker slurry is to be applied, then field experiments to determine the distribution pattern are required to maintain a uniform application of waste.

An idea of the significance of uniformity in waste application by spray irrigation comes from the following discussion taken directly from Norum (1976).

> C_u values commonly used in irrigation design range from 70-95%. The lower values are appropriate for lower valued crops in areas of low-cost water. The higher values are used on high-valued crops irrigated with high-cost water. It has been suggested that a value of 80% or better is appropriate for center pivot systems.
>
> A modified method of characterizing uniformity has been developed by Norum. The significance of the procedure can best be understood by referring to Figure 12, which shows application data for a commonly used solid set system.
>
> If the design application is 2.0 inches (5.08 cm), it can be seen from Figure 12, that about 50% of the disposal site will receive an over-application ranging up to 3.75 in (9.52 cm). If the renovating capability of the soil profile has been accurately determined to be 2.0 in (5.08 cm), then the quality of renovation has been seriously jeopardized in the over-applied areas. This is especially significant if the quality of renovation is to approach drinking water standards. If the design application is based on a nutrient con-

The coefficient of uniformity for center pivot sprinkler systems should be 80% or higher.

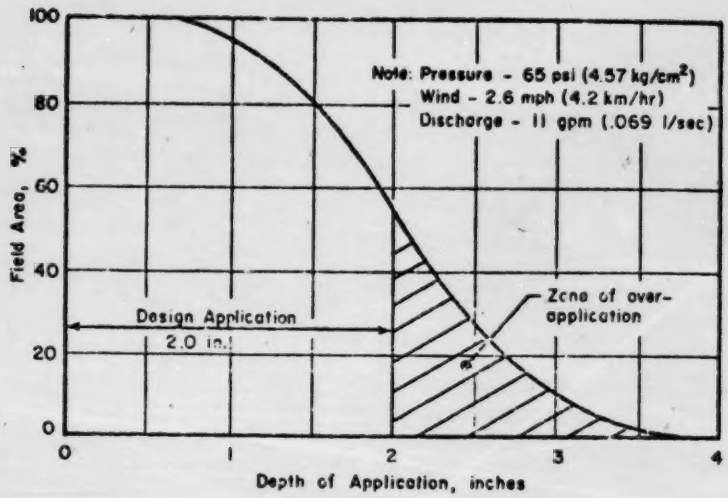


Figure 12. Application uniformity data for a 60 ft x 80 ft solid set system. (Norum, 1976)

straint of 200 lb of nitrogen per acre (224 kg per ha) per year, for example, then an actual range of from about 75 to 375 lb per acre (84 to 420 kg per ha) is possible.

For a given system design many factors affect the actual composite uniformity probable on a disposal site: soil lateral permeability, presence of restricted permeability layers in the soil profile, movement of surface water during application, wind velocity and direction, and operating options. The type of uniformity of application curve to be expected is unique to the system design and site conditions and can only be determined by test. The results of actual tests on equipment commonly used for solid set disposal systems are shown in Figure 13. The abcissa is the actual application divided by the mean application following a method outlined by Norum. The data in Figure 13 help to determine the spacing that should be used. From the curves, the deterioration in uniformity of application is apparent when the same sprinkler is used at increased spacings.

Factors which affect the actual composite uniformity that is probable at a site include soil lateral permeability, presence of restricted layers in the soil, movement of surface water during application, wind velocity and direction, and operating patterns.

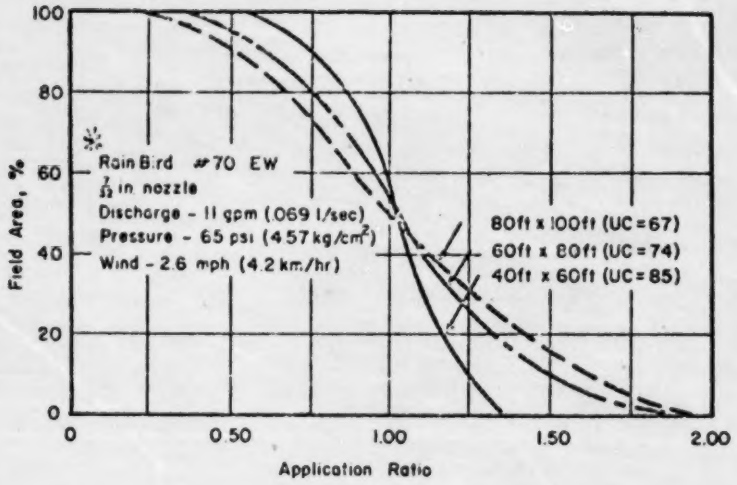


Figure 13. Uniformity of application curves for a typical solid set system. (Norum, 1976)

For the spraying of wastewaters, applications to the disposal site should be limited to the renovating capability of the soil. Following a method suggested by Norum, and using the data in Figure 13, the design applications for the indicated spacings to comply with a 2.0 in (5.08 cm) per week constraint over 90% of the area are:

Application, in.	= 2.0 ÷ application ratio at 10% field area
40 ft x 60 ft	1.63 in. 2.0/1.23 = 1.63 in.
60 ft x 80 ft	1.32 in. 2.0/1.52 = 1.32 in.
80 ft x 100 ft	1.20 in. 2.0/1.67 = 1.20 in.

These data can be used in framing a disposal area versus system cost tradeoff. The 40 ft x 60 ft (12.2m x 18.3 m) spacing achieves good uniformity, and uses a minimum of land, but has a high equipment

capital cost. The 80 ft x 100 ft (24.4m x 30.5m) spacing has poor uniformity, fails to completely charge the root zone and requires more land, but has a lower equipment capital cost. Ultimately the decision on system uniformity must be made on the basis of this kind of analysis. It varies significantly from irrigation procedures and cannot be solved by rules of thumb or generalizations. The consequences of inadequate design are potentially more serious than with irrigation system design.

Surface Application Involves the Choice of Several Techniques

In addition to spray irrigation, several forms of surface irrigation have been used successfully in land treatment of wastewater. Surface application systems also are appropriate for some overland flow treatment schemes and for rapid infiltration basins.

Surface application of wastewater via a gated pipe, open ditches, siphon tubes, or gates for flow distribution are fed by gravity and operated by hand; none of these methods handles large concentrations of solids well.

Wastewater may be applied to the treatment site by gated pipe and by open ditches using spile tubes, siphon tubes, or gates for flow distribution. All these systems are gravity fed and require hand labor to operate. None have good solids handling characteristics due to deposition.

Commercial gated pipe (Figure 14) is generally 6" to 12" diameter aluminum or plastic pipe with openings every 30 to 80 inches. The openings have hand-adjustable gates to regulate flow from each gate. In this way, pressure loss along the pipe can be compensated by larger openings at the far end which will maintain equal volume flow along the length of the pipe. The gated pipe is portable, thus more flexible than ditches for application to the site. For small systems, operators have made "home-made" gated pipe from small diameter polyethylene tubing by cutting holes which are covered with slit segments of the same pipe. Advantages of gated pipe are its portability, low labor requirement compared to other surface applica-

Gated pipes are portable, capable of managing the wastewater and able to work with low labor input; they are more expensive than open ditch systems.

Figure 14. Gated pipe incorporates hand-adjustable openings which can be matched to furrow spacing for row crop irrigation. They provide gravity flow operation and portability. (Adapted from Lindsay, 1977)

tion systems, and good management capability of the wastewater. Costs are higher than the open ditch systems.

Gated pipe is being used with automatic gate systems to eliminate most hand labor.

Gated pipe distribution has been used in a successful row crop irrigation system in California which uses air-actuated valves to open and close the gates on an automatic cycle (Narum, et al., 1976). This system retains the advantages of low pressure operation and good water distribution of other gated pipe systems, while eliminating hand labor of wastewater distribution in the field.

Spile tubes and irrigation siphon tubes are cheap but require a lot of maintenance and labor to work properly.

Spile tubes are stoppered straight pipes placed through the berm of irrigation ditches. Irrigation siphon tubes are sections of bent tubing which are filled with water, then inverted across the side of the ditch. Both these systems are very low-cost, but may require considerable maintenance and labor for normal operation. Ditches feeding these dispersion devices usually are fitted with gates to control flow into the various segments. Ditches also can be fitted with turnout gates which take the place of spile tubes and siphons.

Any of the distribution methods listed above can be used for border irrigation, furrow irrigation, and corrugations.

Surface Irrigation Utilizes Gravity Flow for Application

Border irrigation is well suited to close growing crops such as pasture grasses; its effectiveness depends on obtaining an even sheet of water entering the field.

Border (or border strip) irrigation requires low berms in parallel rows running in the direction of maximum slope of the site. A field is contained between each pair of berms. This method is well suited to close-growing crops such as forages and pasture grasses. The Werribee Farm land treatment system in Melbourne, Australia has used this method of application since 1897. Their current practice is to irrigate to a depth of 4 inches once every 18-20 days. The fields at Werribee are mechanically subsoiled and graded. The effectiveness of this method depends to some degree on obtaining an even sheet

of water entering the field area. This is not always possible, and some minor problems have been reported. For example, at Werribee, which applies raw wastewater, solids deposition occurs near the upper end of the fields. Border irrigation fields may be constructed with a grader or similar piece of earthmoving equipment.

Furrow irrigation is suited for row crops.

Furrow irrigation provides a uniform means of wastewater application for row crops. Contour plowing can enable furrow irrigation on land slopes up to 10%; otherwise a slope of 1% is the usual advisable maximum. Furrow spacing can be matched with gated pipe outlets for direct application from the pipeline.

Corrugations are well suited to close-growing crops on steep, irregular land.

Corrugations are shallow v-notches spaced about 30-40 inches apart and created with a tool bar implement towed by a tractor. Corrugations are well suited to close-growing crops on steep, irregular land.

In surface-applied waters the goal is to obtain a uniform wetting front throughout the soil profile.

In place of the uniformity coefficient concept in sprinkler systems, surface-applied waters are designed to attain a uniform wetting front within the soil profile. This is accomplished by balancing the infiltration rate of the soil with the irrigation stream size, the area to be irrigated, the amount of water to be applied, and the slope of the land.

Application efficiencies of only 40 to 60% can be expected from most surface irrigation systems.

Application efficiencies attained through surface irrigation reflect the uniformity of the wetting front within the soil profile. In systems with good planning, proper construction, and careful operation, an application efficiency of 70% can be expected. However, this requires applying the irrigation water twice per irrigation period which involves twice the labor of a single set. Application efficiencies on the order of 40 to 60% are probably more realistic. Tailwater runoff would have to be collected and returned to the treatment medium if the desired quality were not met.

Overland Flow Systems are Installed on Gentle Slopes

Of special importance to the overland flow treatment system is the consideration of erosion in design. The slopes involved in this treatment alternative would not normally produce erosion, but large rainfalls coupled with wastewater application could have this result. The erosion hazard is minimized by forming small berms at intervals on the treatment site surface.

Erosion must be kept to a minimum if the overland flow system is to work effectively

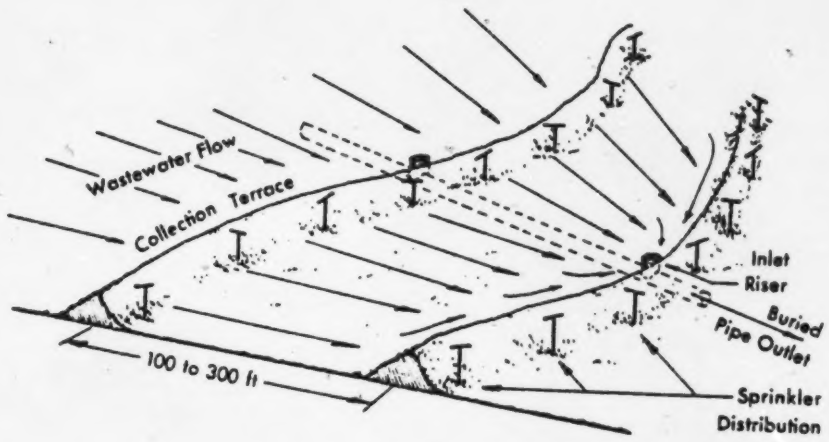


Figure 15. Overland flow wastewater distribution system.

The flow of wastewater over gently sloping (2 to 8%) terraces which are covered with grass characterizes the overland flow system. Wastewater distribution generally has been through the use of sprinkler irrigation systems located at the top of the grassed slope. These slopes are broken at distinct intervals by a series of cross terraces which collect the renovated wastewater and deliver it to a central collection and discharge point, as shown in Figure 15.

Wastewater flows over gently sloping terraces (2% to 8%) in overland flow systems.

Design objectives: There are two main objectives in the design of application systems to serve overland flow treatment sites.

1. Prevent erosive flows along the sloping treatment medium and in the graded collection terraces during rainfall/runoff events.
2. Provide a hydraulic loading rate which will result in the desired effluent quality.

Two goals in overland flow application systems are to prevent erosive flows and to maintain the hydraulic loading rate which will result in the desired effluent quality.

Erosive flows such as sheet and channel erosion have been studied for many years. The U.S.D.A. Soil Conservation Service has done extensive work over the last 40 years in the area of sheet and rill erosion. The Corps of Engineers, Bureau of Reclamation, Department of Transportation, Forest and Park Services, etc. have studied slope stabilization and channel flow. The object of these studies has been to provide non-erosive flows of water over a soil surface.

To prevent erosive flows, the Universal Soil Loss Equation has been used to determine the spacing between terraces. This spacing is based upon an allowable soil loss which in turn is based upon both the physical characteristics of the soil profile in question and the economic conditions resulting from soil erosion. A terrace spacing of 100 to 300 feet is generally found in tilled soils. Agricultural Handbook No. 282, "Predicting Rainfall-Erosion Losses From Cropland East of the Rocky Mountains" fully develop the Universal Soil Loss Equation. More site specific technical information may be obtained from the Soil Conservation Service office which covers the geographical area in question. Site specific parameters have not, as yet, been developed for all areas of the United States. The 100 to 300 ft. terrace spacing has also been found to be most effective in terms of wastewater renovation efficiency in over-

To prevent erosive flows, spaces between terraces should be according to the Universal Soil Loss Equation.

Spaces of 100 to 300 feet between terraces are effective for renovating wastewater in overland flow systems.

land flow systems.

Terraced, grassed slopes are the best erosion control measures available. It is fortunate that this system of vegetative cover and terraced slopes, can also be used for waste management purposes. The terraces not only break up the length of slope but they also provide a system for runoff collection.

Terraced, grassy slopes control erosion, renovate wastewater efficiently, and provide a system for runoff collection.

Overland flow systems have a distinct advantage over other systems, in that the effluent is collected and may be recycled back through the storage and treatment medium if the desired effluent quality has not been attained.

If effluent collected from an overland flow system does not have the desired quality, it can be recycled through the system-a distinct advantage of overland flow over other application systems.

Rapid Infiltration Beds Generally Use Surface Application

In rapid infiltration systems, wastewater may be applied by spray, but surface distribution and application systems are more usual. Rapid infiltration beds can be constructed in much the same manner as border strip irrigation fields, with one berm serving as a wall between two beds. Vegetative cover can also be used in rapid infiltration beds to enhance the infiltration rate of the soil. Other rapid infiltration systems use graded aggregate over the soil surface.

Sludge Application Requires Special Equipment

Sludge slurries may be sprayed, spread through outlets mounted on a portable tank, or placed under the soil surface by special plow attachments.

Gun sprinklers, traveling or stationary, can handle sewage sludge or liquid animal manure slurries of around 15% solids (Peterson, 1975). Specifications for this application include a nozzle diameter of at least 3/4 inch and minimum sprinkler pressure of 70 to 80 psi. Power requirements for pumping to supply such a system would be about 30 hp. Some models of traveling gun sprinklers use turbine and cylinder drive units to move along the cable, and these

Gun sprinklers can handle sludge or slurries with about 15% solids.

may restrict the diameter of solid which may pass the unit to as little as 3/8 inch. No such problem is encountered with travelers using internal combustion engines or drive units mounted on the cable winch at the end of the run.

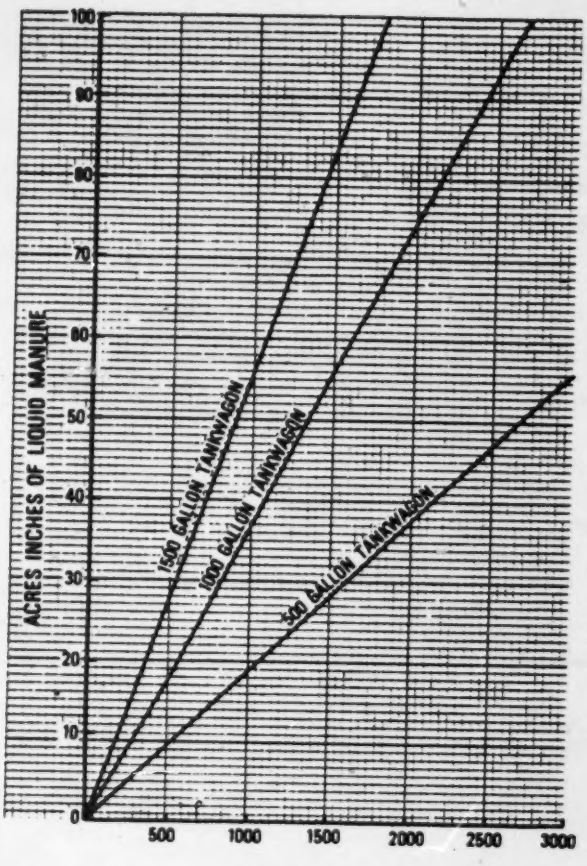
If possible, it may be advisable to pump wastewater or water from another source (other than a potable supply) through the gun sprinkler following each sludge application. This will wash solids off foliage (some problems have been noted with crop burning due to high chemical concentrations in slurries), clean out the pipe, and clean the sprinkler and the external surfaces nearby. If wastewater is not available, a farm pond is an excellent source if auxilliary pumping equipment can be used.

Water from another source should be pumped through the gun sprinkler after each sludge application if possible to wash off foliage and to clean the pipe and sprinkler.

Tankwagons for manure or sludge slurries are normally 1000 to 2000 gallons capacity, with some being over 5000 gallons. Tanks designed to be pulled through tilled fields use oversize tires. Wagons can be economical for hauling wastes to distant fields, which would be costly to use with irrigation systems. Curves of number of trips necessary to dispose of given volumes of waste have been developed (Figure 16) and aid in economic assessment of this alternative.

Tankwagons can have outlets, usually consisting of a manifold with deflectors on the openings, for direct surface application. Odors and high concentrations of pollutants in runoff waters can ensue from surface spreading. This has led to the development of subsurface plow spreaders. Shallow injection with good mixing of sludge and soil produces rapid drying and maintains aerobic conditions. Injection depths of no more than 4-6 inches should be used. Tractors pulling these chisel plow systems may also be fitted with a sludge tank, which must be of a limited size, thus maximizing sludge transport problems. Systems

Subsurface plow spreaders can shallowly inject sludge slurries and manure into the soil, producing rapid drying and maintaining aerobic conditions.



- Number of Trips with Liquid Manure Tankwagon

UNITS

1 acre-inch	= 27,154 gallons	= 3,621 cu. ft.
1 acre-foot	= 12 acre-inches	= 325,848 gallons = 43,560 cu. ft.
1 acre-inch/hour	= 450 gallons/minute	= 1 cubic foot/second

Figure 16

Economic analysis of sludge application systems may be related to the number of trips necessary to apply a certain volume with various sizes of tank wagons (Peterson, 1975).

for sludge injection which use the same flexible hose used with traveling big gun sprinklers are commercially available. The hose connects a large mobile tank with the tractor plow attachment. In this way trips between sludge source and field with the tankwagons are minimized, and operating costs are reduced.

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CHARACTERISTICS OF MAJOR TYPES OF SPRINKLER IRRIGATION SYSTEMS

Type of System	Maximum Field Slope, %	Ave. Water App. Rates in./hr Min	Ave. Water App. Rates in./hr Max	Field Shape	Field Surface Conditions	Max. Crop Height, ft	Labor Required, hrs/ac/irr	Size of Single System, acres	Approximate Cost, $/acre[a]	Wind Drift Hazard	Solids Handling Capability	Comments
Portable solid set[b]	no limit	0.05	2.0	any shape	no limit	no limit	0.20-0.50	no limit	400-900	average	poor	Well suited for field crop and forest disposal sites.
Buried solid set	no limit	0.05	2.0	any shape	no limit	no limit	0.05-0.10	no limit	400-1000	average	poor	Well suited for small systems spraying field crops where completely automated operation is required.
Side wheel roll	5-10	0.10	2.0	rectangular	reasonably smooth	3-4	0.10-0.30	20-80	100-300	average	poor	Best suited for periodic spraying of industrial wastes (such as cannery wastes) on field crops.
Traveler	no limit	0.25	1.0	rectangular	roadway for hose and sprinkler unit	no limit	0.10-0.30	40-100	120-250	high	excellent	Well suited for spraying sludge on field crops.
Center pivot	5-15	0.005	0.090	circular	clear of high obstructions, paths for towers	8-10	0.05-0.15	40-160	180-350	low	average	Well suited for large-scale spraying of wastewater on field crops.

[a] Does not include cost of water supply, pump, power unit, and mainline. Best source of equipment and data is irrigation system vendors.
[b] Towline lateral system is same except that field shape is not as flexible, labor requirements are substantially less.

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WASTE APPLICATION SYSTEMS

Objectives

Upon completion of this module, the participant should be able to:

1. List the application systems alternatives which are applicable to each of the following:

    a. spray irrigation
    b. surface irrigation
    c. overland flow
    d. rapid infiltration

2. Discuss the advantages and disadvantages of the seven types of spray application covered in the module.

3. Discuss the crop limitations of the surface irrigation methods, and identify the spray systems which impose limitations on crops which may be grown.

4. List the application methods appropriate for sludge and discuss their advantages and disadvantages.

5. Discuss the importance of uniformity of application in land treatment.

RETURN TO LESSON PACKAGE

Script to Accompany the A-T

WASTE APPLICATION SYSTEMS

Module 12

January, 1978

WASTE APPLICATION SYSTEMS

This audio-tutorial lesson examines the methods by which wastewater and sludge can be applied to the land application site (Slide 1). The engineer must distinguish between choosing the best way to apply wastewater after the type of land treatment has been determined. The first decision is based upon the soil characteristics, the capacity of the soil to transmit water, the topography, the depth to groundwater, and the vegetation on the available site (Slide 2). After this decision - to use irrigation, overland flow, or rapid infiltration - the selection of the most appropriate method of distributing and applying wastewater or sludge to the site must be made (Slide 3). This lesson describes the various application systems and indicates the advantages and disadvantages of each. There is an envelope containing the objectives for this lesson in the box in which this lesson came. Turn off the tape and study the objectives (Slide 4). You may keep the objectives for reference during the lesson.

If the engineer decides that the site is best suited to irrigation, he or she is presented with the options that were shown before and repeated in Slide 5 for spray or surface application of wastewater onto the land. Most of these options are also suitable for overland flow and rapid infiltration. Options for sludge application are shown in Slide 6.

Let us first examine the options if the engineer chooses spray irrigation as the land treatment method. The major choices of sprinkler irrigation are shown in Slide 7. A copy of the Table in Slide 7 is with the printed material that was with this A-T lesson. Obtain a copy and keep it for reference. Generally, the topography of the site, the infiltration and percolation rate of the soil, and the planned vegetative cover will influence the decision about which spray irrigation system to use. Large rotating sprinkler rigs can be used on slopes up to 25% although such rigs have produced erosive flows on the steeper slopes. It is important to investigate the ability of the soil to maintain its structure under the weight of irrigation rigs as well as from crop management equipment (Slide 8).

Sprinkler irrigation is the most commonly used method of wastewater application in the country. Wastes containing less than 10% solids are readily dispersed in these systems. The solids must be small and distributed throughout the wastewater in order to achieve uniform application and to avoid clogging the system. Gross solids must be removed to protect pumps and spray nozzles from clogging and undue wear (Slide 9). Care must be taken that the sprinklers can handle the solids encountered in a waste treatment system (Slide 10).

All spray systems are designed to be relatively portable except the permanent solid set system. The portability of these systems within the treatment site depends upon the irrigation scheduling and management scheme employed. Even the large center pivot systems can be towed from one water source to another by a farm tractor. Because of the intensity of use expected in wastewater renovation, however, the center pivot systems may remain in one location and be considered permanent (Slide 11). Main lines for all the sprinkler irrigation systems should be permanently buried to protect them from freezing weather as well as accidents involving large machinery (Slide 12).

Spray application is appropriate for crop irrigation and, in some cases, overland flow systems. It also allows application on sandy soils where a high infiltration rate would make surface irrigation very difficult. Spray systems are often the most economical for irregularly shaped or rolling terrain (Slide 13). Spray systems are more expensive than surface systems to install initially, but they generally require less labor and can more easily be automated.

Solid set systems (Slide 14) can be permanently buried or laid on the ground surface and moved by hand between irrigated fields. If portable, the equipment can be collected and stored during the non-application season. Mainlines and laterals are laid out in a grid pattern over the irrigated areas (Slide 15). Overlap between sprinklers varies between 30 to 60% of the wetted diameter. This overlap is needed for uniform water distribution. An idealized grid layout is shown in Slide 16.

The entire solid set system can be scheduled using a time clock and programmed to run continuously. Equipment manufacturers have developed an array of automatic valves which may be regulated from a main control

point. This eliminates much of the hand labor, but it necessitates constant surveillance.

Slide 17 shows the layout of a permanent solid set system in an orchard. The sprinklers are spaced to give the most efficient coverage and the lateral pipelines are laid diagonally to the main. This configuration is most economical, minimizing the overall length versus the size of laterals required. It needs only half the number of valves and connections to the main line that a system employing laterals along each row does. The advantages and disadvantages of the permanent solid set system are indicated in Slide 18.

If a handmove solid set spray irrigation system were used for application, the rectangular grid layout would probably be favored due to the ease of moving laterals along the straight rows. The extra money spent on valves and fittings in this case would be made up by having only enough laterals and nozzles for partial coverage of the site and moving them between sets. The advantages and disadvantages of a handmove solid set system are shown in Slide 19.

The center pivot spray irrigation system (Slide 20) is composed of a complex system of towers, pipes, guy-wires, and motorized wheels. Such systems, diagrammed in Slide 21, cover up to 640 acres with a half-mile long boom. Circular distribution patterns result from center pivot units as shown in Slide 22 although telescoping end units have been developed to cover triangular corner pieces also. These systems can distribute large volumes of water which may cause localized saturation of the soil (Slide 23). Because the weight of the entire system rests upon the various tower wheels, the tires can easily become mired down in mud. This problem can be minimized by decreasing the application rate and using a specially designed tire shown in Slide 24.

The Muskegon County Wastewater Management System utilizes 54 center pivot spray irrigation rigs to irrigate about 5,400 acres of farmland with municipal and industrial wastewater. The layout of the Muskegon system is shown in Slide 25.

Slide 26 shows the sprinkler patterns used in center pivot spray irrigation systems. The spray flood jet pattern, with its downward spraying nozzles results in the most uniform distribution of water with the least soil compaction. The energy requirements are lower than for

the other patterns and there is less aerosol drift. The variable sprinkler spacing pattern uses more energy but also results in a uniform distribution of water with more of an aerosol problem than the spray flood pattern. The fixed sprinkler spacing requires the most energy to run and results in the least uniform distribution of wastewater, therefore it is the least desirable for land treatment.

In summary, the advantages and disadvantages of center pivot systems are summarized in Slide 27.

The next spray system we will examine is the side-roll, wheel move system (Slide 28). Side-roll, wheel move systems with and without trail tubes are shown in Slide 29. In using this system, the cover crop should not grow any higher than 4 feet when mature because the wheels are only available in sizes up to 8 feet in diameter. The system is stationary during spraying (Slide 30). It is then moved to the next set. An engine mounted in the middle of the pipe-axle propels the system from one irrigation set to another. The advantages and disadvantages of the side-roll, wheel move system are shown in Slide 31.

As shown in Slide 32, the continuous travel distribution system utilizes a flexible supply line which is dragged along behind the continuously moving lateral line. The advantages and disadvantages of the continuous travel distribution system are shown in Slide 33. Notice that they are the same as for the side-roll, wheel move distribution system.

Another method of spray irrigation is the towline lateral system. The towline lateral with its stabilizers can be designed to straddle rows of crops as shown in Slide 34. Towline laterals are towed (Slide 35) from one irrigation set across the main delivery line to another set, following a scheduled pattern. Slide 36 shows one suggested pattern of movement.

The towline lateral system has stronger couplings between the pipe sections, but it is otherwise much the same as a handmove set system. The advantages and disadvantages of the towline lateral system are shown in Slide 37.

There are two types of big gun systems (Slide 38). The travelling big gun, indicated in this Table, and the less common stationary big gun. In the travelling big gun system, the nozzle is mounted on a cart with a flexible supply line (Slide 39). The cart may either be towed by a cable or have hydraulic motors for propulsion. One common size will irrigate

10 acres per set. The big gun is capable of spraying sludge slurries with its large diameter nozzle as well as wastewater (Slide 40). A typical layout for a travelling big gun is shown in Slide 41. A stationary big gun (Slide 42) is essentially the same as the travelling big gun except it is moved between sets by hand. It is capable of irrigating about two acres at a set. The advantages and disadvantages of the big gun systems are indicated in Slide 43.

In all methods of spray irrigation, it is important to achieve a uniform application rate. In the design of spray irrigation systems, each unit area of soil is expected to accept a designated volume of wastewater. If, however, the wastewater volume is not applied evenly to the renovation site, expected treatment is not achieved.

Slide 44 indicates an ideal application situation. The whole field is receiving two inches of water. As the bottom diagram indicates, an overlap of between 30 and 60% is generally needed to achieve high uniformity. There are methods for obtaining a uniformity coefficient that involve observing the amount of water collected by containers laid out in a grid on a spray field. A coefficient of uniformity for sprinkler irrigation can be as high as 90%. Values in the mid 70% range are more common. A uniformity coefficient of 80% can be expected for center pivot systems.

Slide 45 shows the factors which influence the uniformity of application. Standard specifications in any sprinkler irrigation design are shown in Slide 46. Slide 47 shows the different distribution patterns which result if operating pressures are not maintained as designed. These curves are used in conjunction with the desired sprinkler spacing to attain a uniform application. If the design pressures are not maintained, very large quantities of water could collect over individual areas, possibly exceeding the infiltration or percolation capacity of those areas and causing saturation and ponding as well as overloading the renovation capacity of the soil in that portion of the site.

The actual uniformity of application is affected by the variables indicated in Slide 48. Thus the uniformity of application curves depend upon both equipment, site, and configuration variables. This is indicated in Slide 49. Using these data it is possible to design a system that will not exceed an application limit in any portion of the proposed site.

An efficiency versus cost tradeoff can also be formulated from this information. The 40' x 60' spacing achieves good uniformity of application, with the minimum amount of land, but may be prohibitively expensive. For some cases, the 60' x 80' spacing may be adequate even though the coefficient of uniformity is significantly lower.

All of the methods of application that have been discussed so far are spray application methods. The next section concerns surface methods of applying wastewater (Slide 50). Surface application can be used for irrigation, overland flow, or rapid infiltration systems. By definition, surface application avoids problems with aerosols and aerosol drift and may, therefore, be the methods of choice for many land application systems. Border, furrow, and corrugation surface methods of wastewater application are each useful for different situations (Slide 51).

Border, border strip, or flood irrigation requires low berms in parallel rows running in the direction of maximum slope of the site (Slide 52). A field is contained between each pair of berms. Border irrigation is well suited to close growing crops such as forages and pasture grasses. The Werribee Farm in Melbourne, Australia has used flood irrigation since 1897. The fields of Werribee are mechanically subsoiled and graded. The success of border irrigation depends to some degree on obtaining an even sheet of wastewater flowing onto the field, a constraint that may require extensive site preparation and grading.

Furrow irrigation offers a means of applying wastewater uniformly on row crops (Slide 53). Contour plowing can enable furrow irrigation on slopes up to 10%. Otherwise, a 1% slope is the maximum slope advised. Furrow spacing can be matched with gated pipe outlets which are discussed below, for direct application from the pipeline. Slide 54 shows furrow application of sludge in California.

Corrugations are shallow v-notches spaced about 30 to 40 inches apart and dug with a tool bar implement towed by a tractor (Slide 55). Corrugations are well suited to close growing crops on steep, irregular land.

Equipment for surface application includes commercial gated pipe, spile tubes, and irrigation siphon tubes. Irrigation ditches may also be fitted with turnout gates.

Commercial gated pipe as shown in Slide 56 is generally 6 to 12 inches in diameter and made of aluminum or plastic with an opening every 30 to 80 inches. The openings have adjustable gates to regulate flow from each gate. In this way, pressure loss along the pipe can be compensated for by larger openings at the far end which will maintain equal volume flow along the length of the pipe. The gated pipe is portable, making it more flexible than ditches for applying wastewater to the site.

For small systems, operators have made "homemade" gated pipe from small diameter polyethylene tubing. They cut holes in the tubing and cover the holes with slit segments of the same tube.

The advantages and disadvantages of using gated pipe to surface irrigate are shown in Slide 57.

Spile tubes as shown in Slide 58 are stoppered straight pipes placed through the berm of irrigation ditches. Irrigation siphon tubes as shown in Slide 59 are sections of bent tubing which are filled with water, then inverted across the side of the ditch. Both spile tubes and irrigation siphon tubes are inexpensive, but both require a great deal of maintenance as well as labor to operate. Ditches feeding these dispersion devices usually are fitted with gates to control flow into the various segments (Slide 60). Ditches can also be fitted with turnout gates which can take the place of siphon tubes and spile tubes.

Application efficiencies attained through surface application methods reflect the uniformity of the wetted front within the soil profile. A uniform front is accomplished by balancing the infiltration rate of the soil with the size of the irrigation stream, the amount of water applied, and the slope of the land. Slide 61, taken at Werribee Farm shows a good coverage and results in excellent wastewater renovation.

This module has dealt with methods of applying wastewater using irrigation systems for illustration. Most of the methods of application - both surface and spray - lend themselves to the overland flow and rapid infiltration systems of waste treatment. Slide 62 shows an overland flow system being supplied by solid set sprinklers, however, the wastewater could be applied using a surface method. Surface methods are more common than spray methods for rapid infiltration systems. Obviously, however, big guns and center pivot type methods do not lend themselves to either overland flow or rapid infiltration systems of land treatment.

We will now examine ways in which sludge can be applied to the land (Slide 63). Sludge slurries may be sprayed, spread through outlets mounted on a portable tank or placed under the soil surface by special plow attachments (Slide 64).

Gun sprinklers, travelling or stationary, can handle sewage sludge or liquid manure slurries with about 15% solids (Slide 65). Specifications for this application include a nozzle diameter of at least 3/4 inch and minimum sprinkler pressure of 70 to 80 psi (Slide 66). Power requirements for pumping to supply a gun sprinkler is about 30 horsepower. Some models of the travelling gun sprinklers use turbine and cylinder drive units to move along a cable, and these may restrict the diameter of solids which can pass through the unit to as little as 3/8 inch. No such problem results with travelling guns that use internal combustion engines, are mounted on truck chassis, or drive units mounted on the cable winch at the end of the run.

After each sludge application, it is advisable to go over the set with wastewater or water from another source through the gun sprinkler (Slide 67). This washes off solids from foliage, cleans out the pipe, and cleans the sprinkler and external surfaces nearby. Some problems have been noted with crop burning due to high chemical concentrations in slurries left on foliage following application. If wastewater for this cleaning is not available, a farm pond is an excellent source of water if auxillary pumping can be used.

Tankwagons offer an economical way to haul sludge and manure to distant fields (Slide 68). Such tankwagons can hold 1000 to 2000 gallons of manure or sludge slurry, with some having a capacity of 5000 gallons. Wagons designed to be pulled through tilled fields have oversized tires.

These tankwagons have outlets on them, usually consisting of a manifold with deflectors on the openings for direct surface application. However, odors and high concentrations of pollutants in runoff water have resulted from surface spreading. Subsurface injectors have been developed to avoid these problems (Slide 69). Sludge is injected shallowly, and a good mixing of sludge and soil produces rapid drying and maintains aerobic conditions (Slide 70). Sludge should be injected no more than four to six inches beneath the soil. Most of these systems can involve giant tank trucks with high flotation tires to minimize soil compaction in wet

field conditions (Slide 71). These systems are capable of handling the sludge from relatively large treatment plants.

Systems are commercially available using the flexible hose used with travelling big gun sprinklers or an injector (Slide 72). A large mobile tank is connected to a tractor plow. In this way, tankwagon trips between the source of the sludge and the application field are minimized. Pipelines can be connected directly to the injector as diagrammed in Slide 73.

This A-T lesson has described the major methods of applying wastewater and sludge to the land. Each system has its advantages and disadvantages. Decisions on use of wastewater application systems should be related to the specific topography, crop cover, soil conditions, labor requirements, and cost ceiling of the land site and treatment option selected.